Rectifiers in Power Electronics


Start with simple half-wave rectifier (full-bridge rectifier directly follows).

In P.S.S.:

\[
<v_o> = <v_x>
= \frac{v_s}{\pi}
\]  \hspace{1cm} (2.1)
If \( L_d \gg I_d \Rightarrow I_d = \frac{v_s}{\pi R} \) \hspace{1cm} (2.2)

If \( \frac{L_d}{R} \gg \frac{2\pi}{w} \Rightarrow \) we can approximate load as a constant current.

### 2.1 Load Regulation

Now consider adding some ac-side inductance \( L_c \) (reactance \( X_c \approx \omega L_c \)).

- Common situation: Transformer leakage or line inductance, machine winding inductance, etc.

- \( L_c \) is typically \( \ll L_d \) (filter inductance) as it is a parasitic element.

![Figure 2.2: Adding Some AC-Side Inductance](image)

Assume \( L_d \sim \infty \) (so ripple current is small). Therefore, we can approximate load as a “special” current source.

\[
\text{“Special” since } < v_L > = 0 \text{ in P.S.S. } \Rightarrow I_d = < \frac{v_x}{R} > \hspace{1cm} (2.3)
\]

Assume we start with \( D_2 \) conducting, \( D_1 \) off \((V \sin(\omega t) < 0)\). What happens when \( V \sin(\omega t) \) crosses zero?
• $D_1$ off no longer valid.

• But just after turn on $i_1$ still $= 0$.

Therefore, $D_1$ and $D_2$ are both on during a commutation period, where current switches from $D_2$ to $D_1$.

$D_2$ will stay on as long as $i_2 > 0$ ($i_1 < I_d$).

Analyze:

$$\frac{di_1}{dt} = \frac{1}{L_c} V_s \sin(\omega t)$$

$$i_1(t) = \int_0^{\omega t} \frac{V_s}{\omega L_c} \sin(\omega t) d(\omega t)$$

$$= \frac{V_s}{\omega L_c} \cos(\Phi)|_0^{\omega t}$$

$$= \frac{V_s}{\omega L_c} [1 - \cos(\omega t)]$$

(2.4)
Commutation ends at $\omega t = u$, when $i_1 = I_d$.

Commutation Period:

$$I_d = \frac{V_s}{\omega L_c}[1 - \cos u] \Rightarrow \cos u = 1 - \frac{\omega L_c I_d}{V_s} \quad (2.5)$$

As compared to the case of no commutating inductance, we lose a piece of output voltage during commutation. We can calculate the average output voltage in P.S.S. from $<V_x>$:

$$<V_x> = \frac{1}{2\pi} \int_u^\pi V_s \sin(\Phi) d\Phi$$

$$= \frac{V_s}{2\pi} [\cos(u) + 1]$$

from before $\cos(u) = 1 - \frac{\omega L_c I_d}{V_s}$

$$= 1 - \frac{X_c I_d}{V_s}$$

$$<V_x> = \frac{V_s}{\pi}[1 - \frac{\omega L_c I_d}{V_s}] \quad (2.6)$$

So average output voltage drops with:

1. Increased current
Figure 2.6: Commutation Period

2. Increased frequency

3. Decreased source voltage

We get the “Ideal” no $L_c$ case at no load.

We can make a dc-side thevenin model for such a system as shown in Figure 2.7.

No actual dissipation in box: “resistance” appears because output voltage drops when current increases.

This Load Regulation is a major consideration in most rectifier systems.

- Voltage changes with load.

- Max output power limitation
All due to non-zero commutation time because of ac-side reactance. This effect occurs in most rectifier types (full-wave, multi-phase, thyristor, etc.). Full-bridge rectifier has similar problem (similar analysis).

Read Chapter 4 of KSV.